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EXPLOSIVE VOLCANISM AND THE COMPOSITIONS OF THE CORES OF DIFFERENTIATED ASTEROIDS; Klaus Keil[1] and Lionel Wilson[1,2] [1]Planetary Geosciences, Dept. of Geology and Geophysics, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA [2]Environmental Science Div., Institute of Environmental and Biological Sciences, Lancaster University, Lancaster LA1 4YQ, UK

Abstract: Eleven iron meteorite groups showing correlations between Ni and siderophile trace elements that are predictable by distribution coefficients between liquid and solid metal of fractionally crystallizing metal magmas, are interpreted to be fragments of the fractionally crystallized cores of 11 differentiated asteroids. Many of these groups crystallized from S-depleted magmas which we propose resulted from removal of the first partial melt (a Fe,Ni-FeS cotectic) by explosive pyroclastic volcanism. We show that these dense, negatively buoyant melts can be driven to asteroidal surfaces by the combination of an excess pressure in the melt and the presence of buoyant bubbles of gas which decrease the bulk density of the melt. We also show that in typical asteroidal materials, veins will form which grow into dikes and serve as pathways for migration of melt and gas to asteroidal surfaces. Since cotectic Fe,Ni-FeS melt consists of about 85 wt.% FeS and 15 wt. % Fe,Ni, removal of small volumes of eutectic melts results in major loss of S but only minor loss of Fe,Ni, thus leaving sufficient Fe,Ni to form sizeable asteroidal cores.

The abundances of siderophile trace elements of 11 of the 13 known iron meteorite groups are correlated with Ni contents [1] and trace element/Ni ratios can be explained by the distribution coefficients between liquid and solid metal of fractionally crystallizing metal magmas [2-4]. These groups, called the magmatic iron meteorite groups, appear to be fragments of the fractionally crystallized cores of 11 differentiated asteroidal parent bodies. The initial S contents of the magmas from which these meteorites crystallized have been estimated from the abundance patterns of siderophile trace elements and the effects that S has on the distribution coefficients of these elements [2-5]. Many of these groups must have crystallized from magmas that were depleted in initial S contents by factors of up to about 6 from those of reasonable precursor materials, such as ordinary chondrites. Table 1 lists the magmatic iron meteorite groups for which estimates of initial S contents are available [3-5], the ranges of their metallographic cooling rates, their parent body radii calculated from those rates, and the best estimates of the specific radii, using the most plausible cooling rates and parent body models (H. Haack, pers. comm.; [6]). With decreasing S content, meteorite cooling rates increase and, hence, parent body radii decrease.

Hypotheses proposed to explain the S depletions of magmas of magmatic iron meteorite groups include loss by volatilization, by continuous removal as an immiscible liquid, and by removal of metastable liquid layers produced by episodic melting [7]. We propose a new model to account for the S depletions of a number of the magmatic iron meteorite groups, involving explosive volcanism such as that postulated to explain the loss of partial melts from the aubrite parent body [8]. A few hundred ppm of expanding volatiles present in early partial (basaltic) melts on the aubrite parent body (or other differentiated asteroids less than about 100 km in radius), upon ascent of the magma to the surface of the body, would have caused disruption into a spray of droplets moving with velocities in excess of the local escape velocities of small asteroidal-sized bodies. The droplets would thus escape and be lost into space 4.55 Ga ago. As a result, no such basaltic rocks exist as individual meteorites nor as clasts in brecciated aubrites. This concept of pyroclastic volcanism has also been applied to explain the lack of complementary basaltic rocks to the ureilites [9-11], and Muenow et al. [12] have shown how pressure rises in asteroids of at least 10s of MPa due to partial melting cause the growth of pathways (fractures, connecting into dikes) which can deliver these early partial melts to the surfaces of asteroids. We suggest that the depletion in initial S contents of the magmas of some of the magmatic iron meteorites is the result of removal from the parent bodies and loss into space of cotectic Fe,Ni-FeS melts by explosive pyroclastic volcanism. This process is expected to be more effective the smaller the bodies and, thus, could explain the decrease in initial S contents of Fe,Ni magmas with decreasing parent body radii (Table 1) [13].

EXPLOSIVE VOLCANISM AND ASTEROID CORES: Keil K. and Wilson L.

If the precursor material of the magmatic iron meteorite groups was roughly similar in composition to ordinary chondrites such as those of the H group, as seems reasonable, then it contained 16.8 wt. % Fe,Ni and 5.1 wt. % FeS [14], and an unfractionated Fe,Ni-FeS magma derived from such material should have 76.7 wt. % Fe,Ni and 23.3 wt. % FeS. However, upon heating of an asteroid of H group composition, the first partial melt would form at the Fe,Ni-FeS cotectic temperature of about 980°C and consist of about 85 wt. % FeS and 15 wt. % Fe,Ni [15,16]. When all of the FeS in the asteroid has been incorporated into such a melt, the melt represents 6.0 wt. % of the asteroid; because of its high density (5000 kg m^{-3}), the melt occupies about 4.2 % of the volume of the asteroid.

The negative buoyancy of this melt can be entirely compensated by the presence of a few hundred to thousand ppm volatiles at pressures up to several tens of MPa. These pressures are produced by the density change on partial melting, and can cause growth and interconnection of cavities occupied by gas and liquid to form dikes which eventually connect to the surface. The rate at which the pathways are formed can be greater than the rate at which gas bubbles rise through the dense liquid, thus ensuring fairly uniform dispersion of the bubbles throughout the liquid. The subsequent expansion of the pressurized volatiles then drives pyroclastic volcanism [8]. Removal of about 88 wt. % of the Fe,Ni-FeS cotectic liquid from an average H group precursor material would deplete the residue in S content to approximately that of the IVB iron meteorite group, which is the group most highly depleted (Table 1). The percentages are even lower for the magmatic iron meteorite groups with higher initial S contents (Table 1). However, because the cotectic melt is relatively poor in Fe,Ni (15 wt. %) and rich in sulfide (85 wt. %), removal of even 88 wt. % of this melt would result in removal of only about 3.5 wt. % metallic Fe,Ni and leave about 96 wt. % of the original Fe,Ni to form a sizeable core.

Table 1: Estimated initial S contents of magmas of magmatic iron meteorite groups, their metallographic cooling rates (MCR), parent body radii (R), and percentage required loss of cotectic Fe,Ni-FeS liquid (LCL).

GROUP	S(%)	MCR (K/Ma)	R (km)	LCL(%)
II AB	10-17	6-12	100-73; avg.87	0
IIIAB	4-5	3-75	138-31; avg. 85	41
IV A	1.0-1.8	11-500	75-13; avg. 44	82
IV B	0.6-1.2	30-260	47-17; avg. 32	88
H chondrites*	8.6			

* This is the S content of the metallic Fe,Ni-FeS portion of H chondrites.

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